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Revision -

Lunar Reconnaissance Orbiter Project

Lunar Reconnaissance Orbiter
Solar Array Specification

December 16, 2005

LRO GSFC CMO

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RELEASED

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

CM FOREWORD

This document is a Lunar Reconnaissance Orbiter (LRO) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LRO CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

Questions or comments concerning this document should be addressed to:

LRO Configuration Management Office
Mail Stop 431
Goddard Space Flight Center
Greenbelt, Maryland 20771

Signature Page

Prepared by:

Original signed by 1/17/2006
John Lyons Date
LRO Solar Array Engineer
NASA/GSFC, Code 563

Reviewed by:

Original signed by 1/17/2006
Tom Spitzer Date
LRO Power Lead
NASA/GSFC, Code 563

Original signed by 1/17/2006
Dave Everett Date
LRO Mission Systems Engineer
NASA/GSFC, Code 431

Approved by:

Original signed by 1/17/2006
Craig Tooley Date
LRO Project Manager
NASA/GSFC, Code 431

LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

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1.0 INTRODUCTION

1.1 SCOPE

This specification describes the electrical, mechanical, environmental, and verification requirements for the Lunar Reconnaissance Orbiter (LRO) Modular Solar Array (SA) Panels.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents and drawings in effect on the day the contract implementing this specification is executed shall apply to the fabrication and to the electrical, mechanical, and environmental requirements of the SA Panels and Qualification Panel to the extent specified herein. In the event of conflict between this specification and any referenced document, this Specification will govern, with the exception of the Solar Array Statement of Work (431-SOW-000038), in which case the SOW takes precedence.

The following is a list of the applicable specifications and publications.

DOCUMENT NUMBER	TITLE	Revision/Date
431-LIST-000410	Solar Array Deliverable Items List and Schedule	Rev -/ January 17, 2006
431-SOW-000038	Lunar Reconnaissance Orbiter Solar Array Statement of Work	Rev -/ January 17, 2006
431-SPEC-000020	Lunar Reconnaissance Orbiter Radiation Environment Specification	Base/ November 1, 2005
ANSI/ASQC-9001-2000	Quality Management Systems - Requirements	Base/ August 1991
ASTM E-595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Out Gassing in a Vacuum Environment	1993(R03)(E)/ June 15, 1993
JSC-SN-C-00005	Space Shuttle Contamination Control Requirements	Revision D July 20, 1998
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment	E/ August 20, 1999
MIL-STD-889	Dissimilar Metals	B, Change 3/ May 17, 1993
MIL-W-22759/44	Hookup Wire	A, Notice 1/ December 8, 2004
NASA-STD-8739.4	Requirements for Crimping Inter-connecting Cables, Harnesses, and Wiring	Base/ February 9, 1998

3.0 REQUIREMENTS

3.1 DESCRIPTION

The LRO spacecraft (SC) is sketched in Figure 3-1.

Except when the SC is eclipsed by the moon and in a few other cases, the SA is intended to point to within 5º of normal to the sun line.

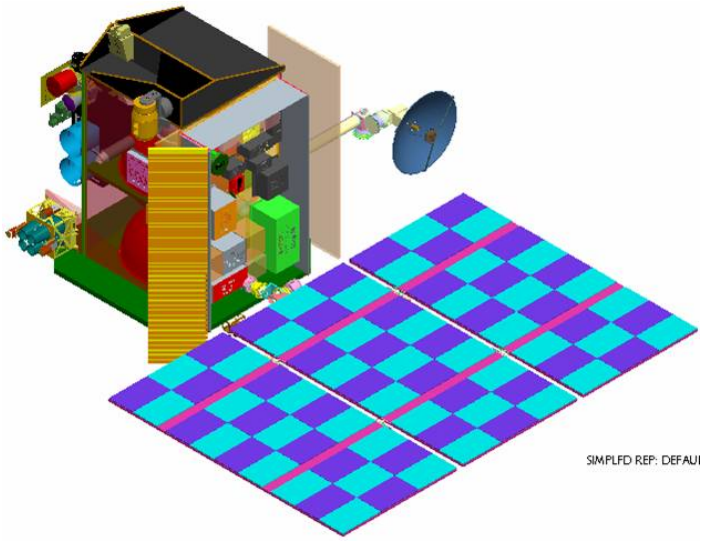


Figure 3-1. The LRO Spacecraft

3.2 UNITS

The Contractor shall use metric units in all documents used for the fabrication of the LRO SA.

3.3 UNITS VERIFICATION

The Contractor shall inspect documents for the use of metric units.

3.4 TEST CONDITION POWER

Under simulated Air Mass Zero (AM0) illumination at 28 degrees Centigrade (º C), the power output from each flight and qualification panel, taken at the solar cell string terminations, shall exceed 40.2 watts (W) at a load voltage of 54.4 volts (V). Under the same conditions, the power output from the test panel assembly shall exceed 80.4W at a load voltage of 54.4V.

3.5 TEST CONDITION POWER VERIFICATION

The Contractor shall use a solar simulator calibrated with a set of balloon-flown primary or secondary standard solar cells to determine the current-voltage (I-V) characteristics of each panel through the panel terminals at 23º ± 5ºC.

The Contractor shall extrapolate the measured data to obtain the I-V curve for a panel operating at 28ºC and AM0.

Type: Measurement.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The verification shall fail if the power at the specified load voltage of a panel does not meet the requirements of Section 3.4.

3.6 POWER AT HIGHEST PREDICTED OPERATING TEMPERATURE

Under simulated AM0 illumination at 120ºC, the power output from each flight and qualification panel, taken at the solar cell string terminations, shall exceed 30.4W at a load voltage of 39.4V. Under the same conditions, the power output from the Test Panel Assembly shall exceed 60.8W at a load voltage of 39.4V.

3.7 POWER AT HIGHEST PREDICTED OPERATING TEMPERATURE VERIFICATION

The Contractor shall use a solar simulator calibrated with a balloon-flown primary or a secondary standard solar cell to determine the current-voltage (I-V) characteristics of each panel through the panel terminals with the panel operating at 120º +10/-0ºC at AM0.

The Contractor shall extrapolate the measured data to obtain the I-V curves for a panel temperature of 120ºC and AM0.

Type: Measurement.

Level: Panel

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The verification shall fail if the power at the specified load voltage of a panel does not meet the requirements of Section 3.6.

3.8 POWER AT HIGHEST PREDICTED SURVIVAL TEMPERATURE

Under simulated AM0 illumination at 135º C, the Contractor shall measure the output of each panel. The total short-circuit current (Isc) of any panel shall never exceed 0.866 amperes at 1.038 AM0, beginning of life (BOL), at the highest predicted survival temperature. Under the same conditions, the total Isc of the Test Panel Assembly shall never exceed 1.732 amperes.

3.9 POWER AT HIGHEST PREDICTED SURVIVAL TEMPERATURE VERIFICATION

The Contractor shall use a solar simulator calibrated with balloon-flown primary or a secondary standard solar cell to determine the current-voltage (I-V) characteristics of each panel through the panel terminals with the panel operating at 135º +10º/-0ºC at AM0.

Type: Measurement.

Level: Panel

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The Contractor shall extrapolate the I-V curve to 135ºC. The verification shall fail if the power at the specified load voltage or Isc of the flight panel, qualification panel, or test panel does not meet the requirements of Section 3.8.

3.10 END OF LIFE POWER

The Contractor shall predict the panel I-V curve, taken at the solar cell string terminations, from the LRO flight panels under 0.962 AM0 illumination at 120ºC, 130ºC, and 135ºC after exposure to the space environment for an interval of fourteen months, which is the contractually defined end of life (EOL) for the array, as well as five years for information. The prediction shall be presented with both graphical and tabular data and shall include the values of Isc, open-circuit voltage (Voc), current at maximum power (Imp), voltage at maximum power (Vmp), maximum power (Pmax), and power at 35V. Among other environments, the prediction shall include the effects of thermal cycling. The number of cycles and their extremes is represented by Table 5-1 for a fourteen-month period.

In computing the EOL power estimates, the Contractor shall use the equivalent fluence method in conjunction with the lunar orbit solar proton environment for one year, 95% confidence level, in Table A-1 and Figure 5-6 of the Lunar Reconnaissance Orbiter Radiation Environment Specification (431-SPEC-000020), as well as the earth-moon transfer electron and proton environments in Appendix D of this Specification.

3.11 END OF LIFE POWER VERIFICATION

The Contractor shall predict current-voltage curves for the flight solar panels for the conditions specified in Section 3.10.

Type: Analysis.

Level: Panel.

Schedule: At Design Conformation Review (DCR).

Pass/Fail Criteria: At 120ºC, after fourteen months, the power of each panel, taken at the solar cell string terminations, shall exceed 24.1W at a load voltage of 35V with the panel normal 5º off the sun line.

3.12 RADIATION HARDNESS

The Contractor shall select all parts to meet their intended application in the on-orbit LRO radiation environment as defined in the Lunar Reconnaissance Orbiter Radiation Environment Specification (431-SPEC-000020). The radiation environment consists of two separate effects: total ionizing dose (TID) and single-event effects (SEE). For the solar cell TID the Contractor shall instead use standard computations to Equivalent 1 Mega-electron Volts (MeV) electrons.

3.13 RADIATION HARDNESS VERIFICATION

The Contractor shall document the radiation hardness assessment for each part with respect to both effects. Test plans and reports for parts that require radiation testing shall be submitted to the National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center (GSFC) Contracting Officer's Technical Representative (COTR) for review.

Type: Analysis

Level: Panel

Schedule: With the DCR Presentation Package

Pass/Fail Criteria: The analysis shall demonstrate that the vendor-selected parts will not fail in the LRO environment.

3.14 BYPASS DIODE FUNCTIONALITY

The bypass diode circuits shall be functional subsequent to panel fabrication and through the end of environmental testing and for the flight panels, through end of life.

3.15 BYPASS DIODE FUNCTIONALITY VERIFICATION

The Contractor shall pass a minimum of 120% of the Isc of each string on each panel through the bypass diode circuits. This test shall be conducted at 23º ± 5ºC with the results extrapolated to 28ºC.

Type: Test.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The voltage dropped by the bypass diodes shall not vary more than ±3% from the first panel level measurement to the last at an extrapolated temperature of 28ºC.

3.16 BYPASS DIODE FUNCTIONALITY AT HIGH TEMPERATURE

The bypass diode circuits shall be functional at high temperatures subsequent to array fabrication and through the end of environmental testing and for the flight panels, through flight.

3.17 BYPASS DIODE FUNCTIONALITY AT HIGH TEMPERATURE VERIFICATION

The Contractor shall pass a minimum of 120% of the Isc of each string on each panel through the bypass diode circuits with the panels at 135º +10º/-0ºC.

Type: Test.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The voltage dropped by the bypass diodes shall not suggest any anomalies in the bypass diode circuit.

3.18 MASS

The Contractor shall add no more than 185 grams to any solar panel substrate.

3.19 MASS VERIFICATION

3.19.1 Substrate Mass Verification

The Contractor shall weigh each substrate received.

Type: Measurement.

Level: Component.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: None

3.19.2 Panel Mass Verification

The Contractor shall weigh each completed solar panel.

Type: Measurement.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The weight verification for the qualification and flight panels shall fail if the mass exceeds the value specified in Section 3.18.

3.19.3 Radius of Curvature

The solar panels shall withstand a radius of curvature of 1143 centimeters (cm) or more without damage.

3.19.4 Radius of Curvature Verification

The Contractor shall perform a bend test on the qualification panel demonstrating that their added components can withstand the specified radius of curvature.

Type: Test.

Level: Flight Panel

Schedule: Per Appendix C

Pass/Fail Criteria: The qualification panel shall pass all the functional tests required by this Specification after the bend test.

3.20 PANEL OUTGASSING

The Contractor shall only use materials with less than 1.0% total mass loss and less than 0.1% Collected Volatile Condensable Materials (CVCM), as determined by the procedures of Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Out Gassing in a Vacuum Environment (ASTM E-595) and shall bake out the panel as defined in Section 3.21.

3.21 PANEL OUTGASSING VERIFICATION

The Contractor shall bake the panels at a temperature of 150ºC+10/-0C in a vacuum of 1×10^{-5} Torr or less for at least 96 hours.

The Contractor shall maintain the Temperature Controlled Quartz Crystal Microbalances (TQCM) at -40C throughout the test to measure total volatile out gassed condensables without the influence of water vapor. The TQCM must have a representative view of the hardware, preferably a vent. The Contractor shall collect and deliver to GSFC: chamber configuration, including chamber size, use of shrouds, TQCM location, cold finger and scavenger plate locations, if used, and general test setup; TQCM readings, taken a minimum every 0.5 hours; hardware temperature; chamber and shroud temperature; TQCM temperature; and pressure.

Type: Measurement.

Level: Panel.

Schedule: Per Appendix B and Appendix C. The out gassing verification shall take place immediately prior to the thermal vacuum cycling test.

Pass/Fail Criteria: The TQCM readings shall be less than 5E-12 g/sq-cm/sec or the Contractor shall notify GSFC.

3.22 SUBSTRATE INSULATION RESISTANCE

The resistance between the substrate and the solar cell circuits shall be greater than 100 megohms for the flight panels and the qualification panel.

3.23 SUBSTRATE INSULATION RESISTANCE VERIFICATION

The Contractor shall make connection to the cell circuits through each panel's terminals and shall tie all positive and negative power leads together. The Contractor shall then measure the resistance between these tied together leads and the panel's substrate. The Contractor shall make this measurement at 500 volts direct current (Vdc) with the current limited to 20 microamperes or less with the positive test voltage on the cell circuits

Type: Measurement. The insulation resistance values shall be recorded.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The panel shall fail verification if its substrate insulation resistance is less than that required by Section 3.22.

3.24 PANEL CONFIGURATION

3.24.1 Parts and Subassembly Layout

The Contractor shall comply with layout, stay out zone, configuration and other requirements specified in Figures 3-2 and 3-3. The Contractor may otherwise locate flight panel parts and subassemblies for convenience so far as the configuration is consistent with this Specification.

Because of the very high operating and survival temperatures characteristic of this mission, the Contractor shall use welding or high-temperature solder for all electrical joints. The Contractor shall not use SN-62 solder. The Contractor may propose a high-temperature method other than those mentioned in this Section if it can provide test data that shows qualification and heritage for this method. Any such alternate method will be subject to GSFC approval.

Each flight, qualification, and test solar panel shall have two solar cell series strings.

The Contractor shall populate a qualification panel on a Government-Furnished Equipment (GFE) substrate that is identical to the flight panels. The Contractor shall fabricate the qualification panel using the same materials and processes that it plans to use for the flight panels. The Contractor shall remove and replace a minimum of four solar cells subsequent to panel fabrication but prior to test. If for some repairs, the Contractor might replace broken covers rather than entire Covered Interconnected Cells (CICs), it shall remove and replace a minimum of four covers, which are not over the replaced cells, subsequent to panel fabrication but prior to test.

The Contractor shall populate test panels on GFE substrates that are identical to the flight panels. The Contractor shall fabricate the test panels using the same materials and processes that it plans to use for the flight panels. The Contractor shall then deliver the test panels to GSFC. GSFC will then attach two or more of the test panels to a structural frame and wire them together in a configuration representative of the flight array. GSFC will then deliver this Test Panel Assembly back to the Contractor for testing according to the requirements of this Specification.

3.24.2 Parts and Subassembly Layout Verification

The Contractor shall propose methods and schedules for verifying the parts and assembly layout.

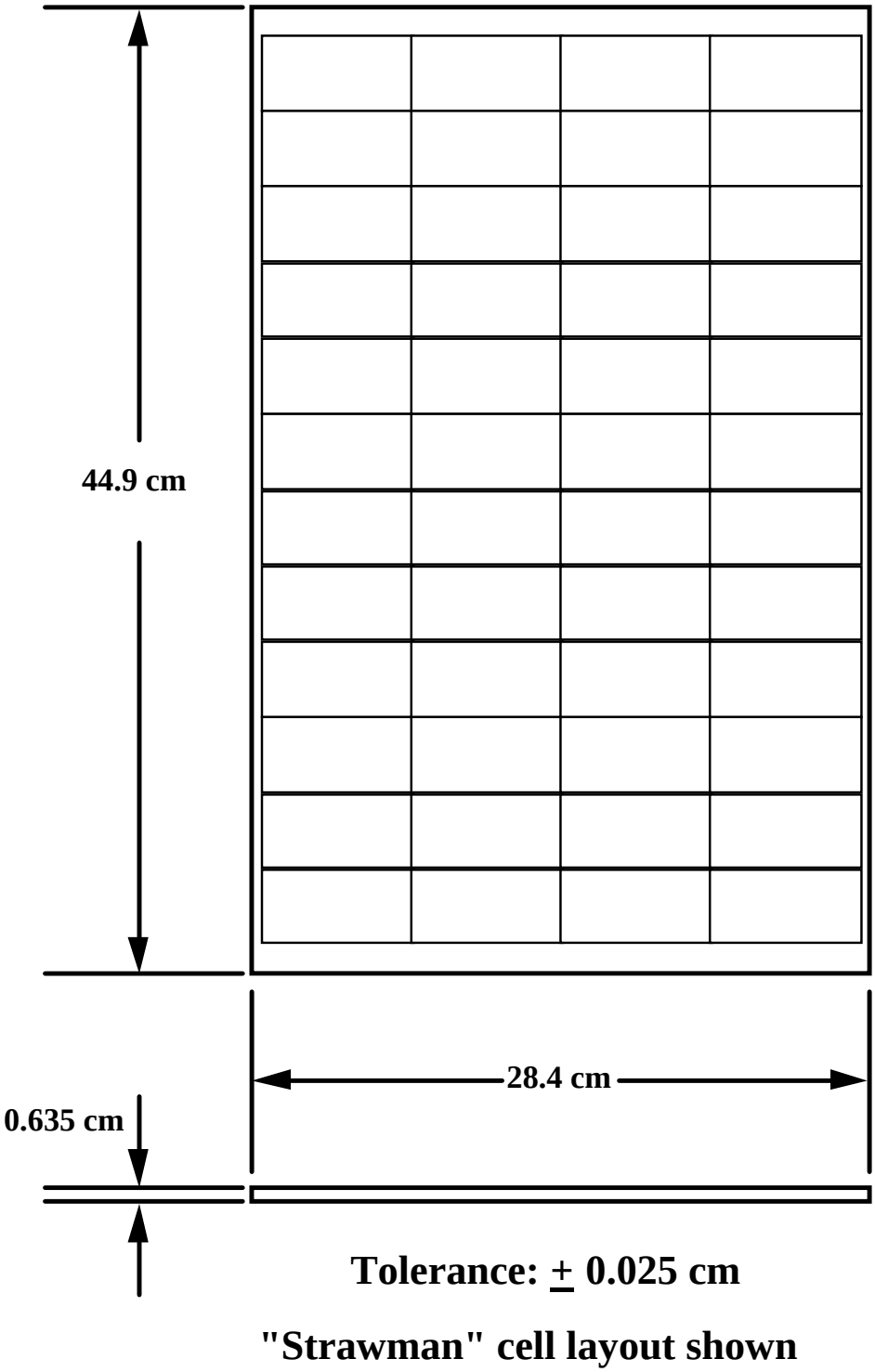


Figure 3-2. Solar Panel Front-Side Configuration

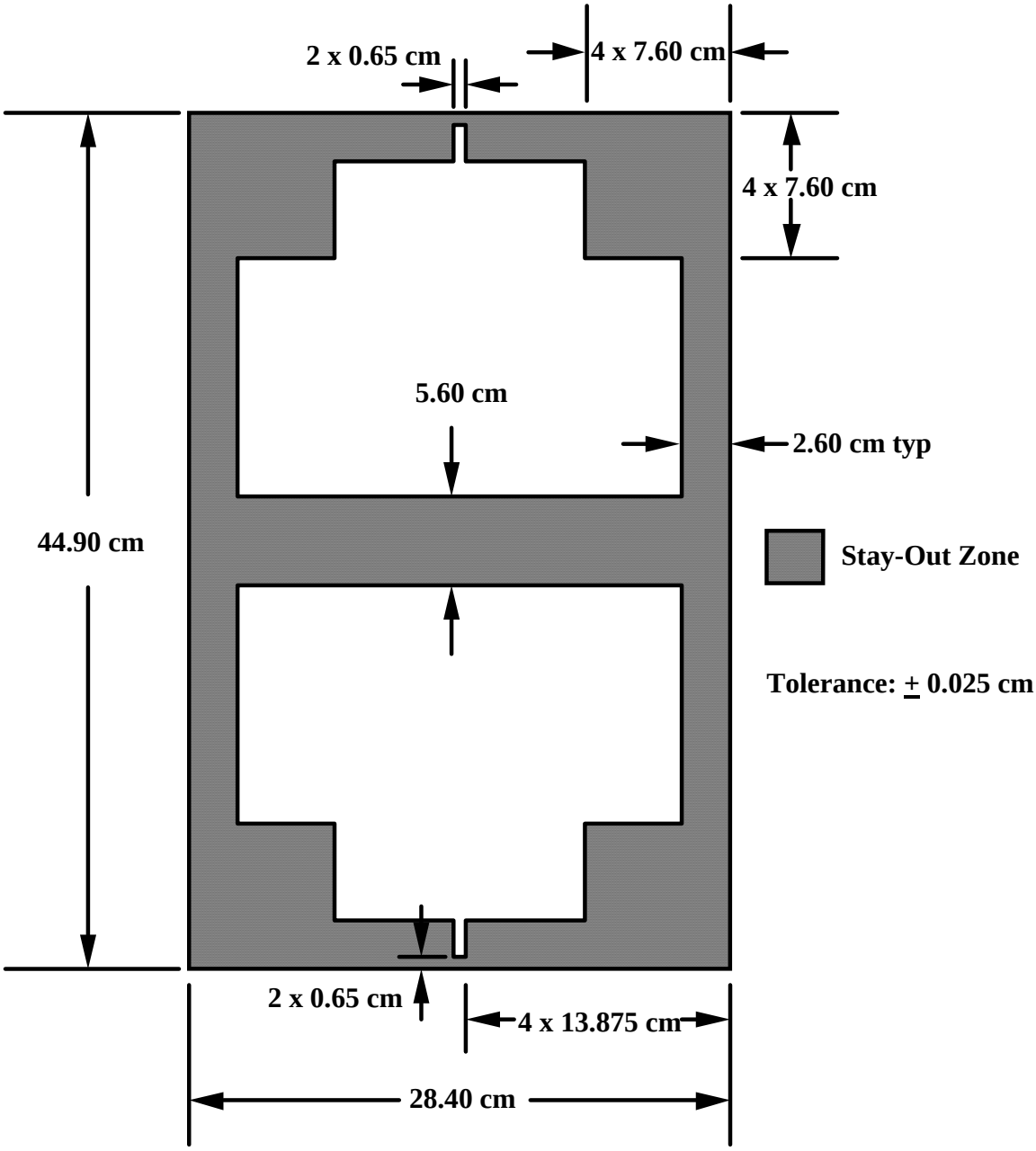


Figure 3-3. Solar Panel Back-Side Configuration

3.24.3 Panel Identification

GSFC has identified the flight, qualification, test, and Isc and Voc Sensor panels as LRO-001 through LRO-092, which shall be marked on the GFE substrates. The Contractor shall not obscure or cover these identifications.

3.25 SOLAR CELLS AND BYPASS DIODES

3.25.1 Cell Mechanical

No cell on a panel shall have a crack, visible at 7 times or less magnification.

3.25.2 Cell Mechanical Verification

The Contractor shall visually inspect each solar cell for compliance with Section 3.25.1. The Contractor shall inspect with the unaided eye and under a minimum of seven-power magnification. The Contractor shall perform optional inspections, which it determines are advisable, at its discretion.

Type: Inspection.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: Each solar cell shall meet the requirements of Section 3.25.1 or the Contractor shall remove the cell from the panel and replace it. If more than 4% of the cells on the qualification panel crack as a result of test, the panel shall fail qualification.

3.25.3 Cell Type

The Contractor shall use space flight qualified triple-junction solar cells having a nominal efficiency sufficient to meet the requirements of this Specification.

3.25.4 Cell Type Verification

The Contractor shall define this verification.

3.25.5 Cell Absorptance

The average absorptance of the covered cells on each panel over the AM0 solar spectrum shall be less than 0.92 when used with the cover specified in this Specification.

3.25.6 Cell Absorptance Verification

The Contractor shall measure the absorptance of five covered cells from the first lot of cells, subsequent to covering, and from a random selection of twenty of the covered cells delivered for the flight panels. If the average absorptance of the cells exceeds that specified in Section 3.25.5, the Contractor shall measure the absorptance of one hundred of the cells delivered for the flight panels.

Type: Measurement.

Level: Component.

Schedule: The Contractor shall perform this measurement on the first lot of cells within a week of their fabrication. The Contractor shall perform the subsequent measurements over the interval during which the cells are being covered.

Pass/Fail Criteria: The measured absorptance shall fail verification if the requirements of Section 3.25.5 are not met after the average of 125 tested cells. The measured absorptance shall pass if the requirements are met after the test of 25 cells or 125 cells.

3.25.7 Limit to Degradation Due to Shadowing

No panel shall experience more than 3% degradation in maximum power output as a result of the panel being repeatedly partially shadowed a minimum of 50 times.

3.25.8 Limit to Degradation Due to Shadowing Verification

The Contractor shall pass 1.1 times the nominal Isc of the solar cells through each solar cell for a minimum of two seconds prior to using the solar cell on the panel.

Type: Measurement.

Level: Component.

Schedule: The Contractor shall run this test within one week of attachment of a discrete bypass diode or within one week after fabrication of the solar cells having monolithic bypass diodes.

Pass/Fail Criteria: The tested solar cells, when assembled into a panel, shall have sufficient power to meet the requirements of Section 3.0 or the verification shall fail and the cells' maximum power output shall degrade less than 3% or the verification shall fail. In case of failure, the Contractor shall scrap the cell and monolithic bypass diode or scrap and replace the cell's bypass diode and retest.

3.25.9 Solar Cell and Bypass Diode Weld and Contact Strength

The welds or solder joints to the solar cell contacts and bypass diode contacts shall be sufficiently reliable so that the fully assembled flight panels and qualification panel meet the requirements of this Specification.

3.25.10 Weld and Contact Strength Verification

The Contractor shall determine minimum acceptable pull strengths from a statistical analysis of the pull strengths for each weld-contact type. The minimum and maximum pull strengths shall each be three standard deviations from the corresponding average pull strengths. The Contractor shall make this determination for every weld schedule and contact type used on the solar cells and every weld and contact type used on the bypass diode.

The Contractor shall maintain a statistical summary of its weld pull strengths for GSFC inspection. At a minimum, the summary shall include the average pull strength and the standard deviation, and those welds, which were more than three standard deviations from the average.

Type: Measurement.

Level: Component.

Schedule: The Contractor shall perform weld pull strengths on each weld type made a minimum of twice per eight-hour shift.

Pass/Fail Criteria: The minimum pull strength shall be greater than 150 grams. The Contractor shall consider pull strengths outside of these limits as a non-conformity, which it shall investigate for cause and solution. During the time of the investigation, the Contractor shall discontinue making the suspect welds. The Contractor shall document each such non-conformity with its cause and solution.

3.26 SOLAR CELL COVERS

3.26.1 Cover Orientation

The covers shall be oriented using an etch symbol such that it disappears when the cover is fixed to the cells. (Stains and crops are not acceptable as they have repeatedly resulted in upside down covers.)

3.26.2 Cover Orientation Verification

The Contractor shall visually inspect each solar cell cover for compliance with Section 3.26.1.

Type: Inspection.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: No more than 0.1% of a panel's covers shall fail this test.

3.26.3 Cover Thickness

The cover thickness shall be approximately 0.0075 cm.

3.26.4 Cover Thickness Verification

The Contractor shall certify that the cover thickness meets the requirement of Section 3.26.3.

3.26.5 Indium Tin Oxide Coating

The Contractor shall use covers that are coated with Indium Tin Oxide having less than 5000 ohms per square and connect each cover either to the array circuitry or ground. The covers shall also have an anti-reflection (AR) coating.

Alternatively, the Contractor may use covers with only an AR coating if it can show that the cover has a resistivity, and the cover adhesive has a resistivity, that allows the LRO SC charge to bleed from the cells through the covers to the plasma.

3.26.6 Indium Tin Oxide Coating Verification

The Contractor shall verify the electrical connection between the geometric center of each cover within ± .5 cm, and its connection to ground or the array circuitry at 23º ± 5ºC or by analysis if using the alternate.

Type: Measurement; analysis if the Contractor selects the alternate.

Level: Panel.

Schedule: Per Appendix B and Appendix C. If the Contractor elects to use the alternate, at the DCR.

Pass/Fail Criteria: 50,000 ohms or, if the Contractor uses the alternate, the analysis shows the SC will bleed to a voltage of less than 40V relative to plasma under any foreseeable environment.

3.27 ISC AND VOC SENSORS

On the GFE Isc and Voc Sensor panel, the Contractor shall install a single CIC sensor and a solar cell series string sensor, each having the same design, manufacture, and general performance of the service CICs and strings. The single CIC sensor will detect in-flight degradation of Voc. The series string sensor will detect in-flight degradation of Isc. The number of Isc sensor string cells in series shall be such that the entire panel besides the Voc sensor CIC is covered as much as is practical. The Contractor shall wire each sensor to terminal posts on a terminal board on the back of the panel using American Wire Gage (AWG) #22 wire. The Contractor shall locate the terminal board such that the wire lengths are as short as is practical. The Contractor shall locate the positive and negative terminal posts for each string sensor as close together as is practical. The GSFC will provide the circuitry to sense Voc and Isc within the SC power electronics.

3.28 ISC AND VOC SENSORS VERIFICATION

The Contractor shall use a solar simulator calibrated with a balloon flown primary or secondary standard solar cell to determine the current-voltage (I-V) characteristics of each sensor through the connector at 23º ± 5ºC.

The Contractor shall extrapolate the measured data to obtain the output at 28ºC and AM0 from the 23º ± 5ºC test.

The Contractor shall measure the output of each sensor during the high temperature tests for information only.

Type: Measurement.

Level: Component.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: At 28ºC, the output from each sensor shall change no more than 3% from immediately after initial assembly to the panel through the last measurement.

3.29 WIRE AND LAYOUT

To make electrical connection, the Contractor shall, where possible, use pairs of twisted wire, each pair consisting of an insulated AWG #24 wire meeting MIL-W-22759/44. The Contractor shall use non-redundant wiring between any solar cell string and the terminal board. The Contractor shall protect the wire wherever abrasion may be a problem. The Contractor shall use stress relief between wire tie points to avoid strains, particularly on the solar cell string terminations. The Contractor shall address how it will stake the wire.

The Contractor shall use red wire for power leads and black wire for return leads.

The Contractor shall meet the requirements for wire placement required by Figures 3-2 and 3-3.

3.30 STRING WIRE AND LAYOUT VERIFICATION

The Contractor shall propose the type, level, schedule and pass/fail criteria for verifying the wire type and layout.

3.31 TERMINAL BOARDS AND BLOCKING DIODES

The Contractor shall design the terminal boards. The Contractor shall insulate the terminal boards from and bond them to each flight, qualification, and test panel with an adhesive or hardware proposed by the Contractor and approved by the GSFC. Due to the stay-out zones in Figure 3-3, it may be necessary to have separate terminal boards for each solar cell series string. For each string positive termination, the terminal board shall contain parallel redundant blocking diodes, which the Contractor shall connect in series with the solar cell string. The Isc and Voc Sensor terminal boards shall not have blocking diodes.

3.32 TERMINAL BOARD AND BLOCKING DIODE VERIFICATION

The Contractor shall propose the method to be used to verify terminal board conformance with the requirements of Section 3.31. The Contractor shall check the forward voltage and reverse current of each diode prior to and after its assembly onto the SA panel and whenever there is reason to question the performance of the diodes as well as according to Appendices B and C.

3.33 BLOCKING DIODE VERIFICATION AT HIGH TEMPERATURE

The Contractor shall deliver blocking diodes to GSFC in accordance with the Solar Array Statement of Work (431-SOW-000038) and the Solar Array Deliverable Items List and Schedule (431-LIST-000410). GSFC will test the diodes to verify their performance at their highest predicted temperature.

3.34 SUBSTRATES

The GSFC shall supply insulated substrates for flight, qualification, test, and CIC panels to the Contractor. Before using the substrates, the Contractor shall verify that they are suitable for bonding SC solar cells.

3.35 SUBSTRATE VERIFICATION

The Contractor shall propose the type level, schedule and pass/fail criteria for verifying that the substrates are suitable for use. The Contractor shall also propose the type, level, schedule, and pass/fail criteria for the performance of the substrates after environmental exposure.

3.36 SUBSTRATE GROUNDING

GSFC shall ground the substrates.

3.37 SUBSTRATE GROUNDING VERIFICATION

The Contractor need not verify the substrate ground.

3.38 CLEANLINESS

3.38.1 Overall Cleanliness

The Contractor shall keep the panels visibly clean to highly sensitive level per Space Shuttle Contamination Control Requirements (JSC-SN-C-0005, Revision D). The Contractor shall use cell, cover and other adhesives to insure that they do not flake throughout panel test and flight.

3.38.2 Cleanliness Verification

The Contractor shall inspect the panels to the requirements of JSC-SN-C-005 to the highly sensitive level using both white and black light inspections.

Type: Inspection.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: The inspection shall meet the visibly clean highly sensitive requirements of JSC-SN-C-005. If not, the Contractor shall clean the “dirty” areas until the requirement is met.

3.38.3 Wiping Materials

The Contractor shall only use extracted wipes to clean the solar panels, solar cells and covers. All wipes or other items used to clean the panels shall be Soxhlet extracted for a minimum of 24 hours and dried before use. (Commercial product is available that meets this requirement.)

3.38.4 Wiping Materials Verification

Type: Inspection.

Level: CIC and Panel.

Schedule: On every use.

Pass/Fail Criteria: Cleaning materials shall meet the requirements of Section 3.38.3 or fail this verification.

3.38.5 Gloves

The Contractor shall only use latex-free, powder-free, polyethylene gloves to touch completed CICs and panels in the presence of solvents. The Contractor shall only use powder-free latex or nitrile gloves on dry CICs and panels.

3.38.6 Glove Verification

Type: Inspection.

Level: CIC and Panel.

Schedule: On every use.

Pass/Fail Criteria: Gloves shall meet the requirements of Section 3.38.5 or fail this verification.

3.38.7 Room Cleanliness

The Contractor shall assemble the solar panels in a Class 300,000 room or better.

3.38.8 Room Cleanliness Verification

Type: Measurement.

Level: Facility.

Schedule: Every six months.

Pass/Fail Criteria: The assembly area shall meet the requirements of Section 3.38.7 or fail this verification.

3.38.9 Assembly Room Temperature

The Contractor shall assemble the solar panels in a room between 18ºC and 28ºC.

3.38.10 Assembly Room Temperature Verification

Type: Measurement.

Level: Facility.

Schedule: Every day.

Pass/Fail Criteria: The assembly area shall meet the requirements of Section 3.38.9 or fail this verification.

3.38.11 Assembly Room Humidity

The Contractor shall assemble the solar panels in a room having a humidity range proposed by the Contractor.

3.38.12 Assembly Room Humidity Verification

Type: Measurement.

Level: Facility.

Schedule: Every day.

Pass/Fail Criteria: The assembly area shall meet the requirements of Section 3.38.11 or fail this verification.

4.0 LIFE REQUIREMENTS

4.1 MISSION LIFE

The solar panels shall have a mission life exceeding fourteen months. The solar panels have a mission life goal of five years, with the life beyond fourteen months in an elliptical lunar orbit.

4.2 MISSION LIFE VERIFICATION

The Contractor shall certify that it has conducted a test program to demonstrate that the solar panels have a mission life greater than fourteen months.

The Contractor shall certify that it has not knowingly limited the mission life of the panels to less than five years.

4.3 SHELF LIFE

The solar panels shall have a shelf life exceeding 10 years.

4.4 SHELF LIFE VERIFICATION

The Contractor shall certify that the solar panels will have a shelf life greater than 10 years when packaged to its specifications.

5.0 PERFORMANCE AFTER EXPOSURE TO ENVIRONMENTS

5.1 THERMAL

5.1.1 Panel Performance in Thermal Vacuum Environment

No panel shall degrade in peak power by more than 2 percent and no panel shall incur damage that may question its reliability to meet the requirements of this document after exposure to the flight thermal cycles in the vacuum of space. These cycles may be as severe as –160ºC to +135ºC (for the case where an eclipse by the moon is followed by an eclipse by the earth, Case 1), or –120ºC to +135ºC (for the case that includes only an eclipse by the moon, Case 2).

5.1.1.1 Panel Performance in Thermal Vacuum Environment Verification

The contractor shall thermal cycle each flight panel, the qualification panel, the Isc and Voc Sensor panel, and the test panel assembly, in a vacuum of 1×10^{-5} Torr or less. The contractor shall cycle the panels at 5ºC beyond the temperature extremes specified in section 5.1.1 for one cycle for Case 1 and seven cycles for Case 2, as defined in Section 5.1.1.

The Contractor shall fix at least two calibrated temperature sensors over each flight and qualification panel, and at least four to the Test Panel Assembly. The Contractor shall cycle to the temperature extremes based on the average reading of the temperature sensors. The temperature gradients across the panels shall be limited to ±20ºC. The period for one cycle shall be greater than 96 minutes, excluding the dwell. The dwell at the temperature extremes shall be greater than one hour. The rate of temperature change between cold and hot limits shall not exceed 30ºC per minute.

The Contractor shall send current through each panel circuit and through the Isc and Voc Sensors during these tests. The Contractor shall continuously monitor the currents with an analog strip chart recorder channel dedicated to that circuit or CIC. At no time, however short, shall the strip chart recorder not monitor the current. This requirement specifically excludes the use of digitizing recorders or point type recorders. The Contractor shall pass current through the cells through the first three cycles, to test the cells, pass current through the bypass diodes through the second three cycles, pass current through the cells through the second to last cycle, and pass current through the bypass diodes through the last cycle. The reverse current through the cells shall be conducted through a connection to the anode terminal side of each string's blocking diode and to each string's return.

During the pump-down, the Contractor shall monitor power line voltages, to demonstrate the absence of corona discharge and multipaction.

Transitions from cold to hot conditions increase contamination hazards because material that has accreted on the chamber walls may evaporate and deposit on the relatively cool solar panels. Transitions will be conducted at rates sufficiently slow to prevent this from occurring. Testing shall start with a hot and end with a hot soak, in this case met by the out gassing verification, see Section 3.21, to minimize this risk.

Type: Measurement.

Level: Panel.

Schedule: Per Appendix B and Appendix C.

Pass/Fail Criteria: Any discontinuity showing in a strip chart recording shall fail the verification. Any defects or reduction of power output outside the limits of the requirements of this Specification shall fail the verification.

5.1.2 Panel Performance in Thermal Environment Verification

The Contractor shall rapid temperature cycle test the qualification panel, connected to Contractor harnesses, in flight configuration including a flight connector in a dry inert nitrogen or vacuum to the temperatures in Table 5-1. The Contractor shall fix at least four calibrated temperature sensors over the panel. The Contractor shall use the average to determine temperature. Temperature gradients across the panel shall be limited to ±10ºC at the extreme temperatures. The dwell time at the temperature extremes shall be at least 10 minutes. The rate of temperature change for the first 10 minutes of hot to cold shall be greater than 10ºC per minute. The rate of temperature change for the first ten minutes going from cold to hot shall be greater than 20ºC per minute.

Table 5-1. Qualification Panel Thermal Cycling

At Least This Number of Cycles	Low Temperature Must be Equal to or Lower than (ºC)	High Temperature Must be Equal to or Higher than (ºC)
2171	-130	+145
2171	-126	+143
1158	-119	+136
1	-170	+145

The Contractor shall send current through each panel string during this test. The Contractor shall continuously monitor the current through each string with an analog strip chart recorder channel dedicated to that circuit. At no time, however short, shall the strip chart recorder not monitor the current. This requirement specifically excludes the use of digitizing recorders or point type recorders. The Contractor shall reverse bias the cells through the first half of the cycles of each of the five temperature ranges, to test the bypass diodes, and forward bias the cells through the second half of the cycles of each of the five temperature ranges. The forward bias cell current shall be conducted through a connection to the anode terminal side of each string's blocking diode and to each string's return.

Type: Measurement.

Level: Panel.

Schedule: Appendix C. The Contractor shall complete tests defined in this section prior to starting the fabrication of the flight panels.

Pass/Fail Criteria: Any discontinuity in any strip chart recording shall fail the verification. Any defects or reduction of power output outside the limits of the requirements of this Specification shall fail the verification. Additionally, the assembly must pass the functional tests required during the intermediate and final inspections and tests.

5.1.3 Test Panel Assembly Performance in Thermal Environment Verification

The Contractor shall rapid temperature cycle test the test panel assembly, connected to Contractor harnesses, in flight configuration including a flight connector in a dry inert nitrogen or vacuum to the temperatures and number of cycles in Table 5-1. The Contractor shall fix at least eight calibrated temperature sensors over the assembly and use the assembly's platinum resistor to monitor temperature. The Contractor shall use the average to determine temperature. Temperature gradients across the panel shall be limited to ±10ºC at the extreme temperatures. The dwell time at the temperature extremes shall be at least 10 minutes. The rate of temperature change for the first 10 minutes of hot to cold shall be greater than 10ºC per minute. The rate of temperature change for the first ten minutes going from cold to hot shall be greater than 20ºC per minute.

The Contractor shall send current through each panel string and the Isc and Voc Sensors during this test. The Contractor shall continuously monitor the current through each string and the Isc and Voc Sensors with an analog strip chart recorder channel dedicated to that circuit. At no time, however short, shall the strip chart recorder not monitor the current. This requirement specifically excludes the use of digitizing recorders or point type recorders. The Contractor shall reverse bias the cells through the first half of the cycles of each of the five temperature ranges, to test the bypass diodes, and forward bias the cells through the second half of the cycles of each of the five temperature ranges. The forward bias cell current shall be conducted through a connection to the terminal anode side of each string's blocking diode and to each string's return.

Type: Measurement.

Level: Panel.

Schedule: Appendix C. The Contractor shall complete tests defined in this section prior to starting the fabrication of the flight panels.

Pass/Fail Criteria: Any discontinuity in any strip chart recording shall fail the verification. Any defects or reduction of power output outside the limits of the requirements of this Specification shall fail the verification. Additionally, the panel must pass the functional tests required during the intermediate and final inspections and tests.

5.2 ALLOWABLE DEGRADATION DUE TO HARD PARTICLE RADIATION

The Contractor shall consider hard particle radiation in its computation of EOL power, see Sections 3.10 and 3.13.

5.3 DEGRADATION DUE TO HARD PARTICLE RADIATION VERIFICATION

The Contractor shall perform in accordance with Section 5.2.

5.4 ALLOWABLE DEGRADATION DUE TO HUMIDITY

The Contractor components added to the flight solar panels shall meet the requirements of this document during and after exposure of 0 to 70% relative humidity after two (2) years.

5.5 ALLOWABLE DEGRADATION DUE TO HUMIDITY VERIFICATION

Type: Certification.

Level: Panel.

Schedule: By DCR

Pass/Fail Criteria: The Contractor shall certify that it meets the requirements of Section 5.4.

5.6 ALLOWABLE DEGRADATION DUE TO DEPRESSURIZATION

The Contractor components added to the flight solar panels shall meet the requirements of this document after depressurization from 1 atmosphere to 1E-05 Torr in 30 seconds.

5.7 ALLOWABLE DEGRADATION DUE TO DEPRESSURIZATION VERIFICATION

Type: Certification.

Level: Panel.

Schedule: By DCR

Pass/Fail Criteria: The Contractor shall certify that it meets the requirements of Section 5.6.

6.0 VERIFICATION REQUIREMENTS

The Contractor shall conduct a verification program in accordance with this document and that otherwise demonstrates the hardware design meets all requirements contained in this document. The Contractor shall provide a verification matrix defining the method of verification for each specific requirement of this document. Verification methods include inspection, analysis, test or a combination of these techniques.

The following definitions and requirements apply, unless otherwise noted, to all the verifications required by this document.

6.1 INSPECTION

6.1.1 Visual Inspection

The Contractor shall perform visual inspection in accordance with the requirements of this Specification.

6.1.2 Physical Measurement

Physical measurement of hardware property (i.e., mass, dimensions, etc.) shall demonstrate that the hardware meets specific requirement.

6.1.3 Documentation Search (Similarity)

Verification of requirements based on similarity shall include supporting rationale and documentation and shall be approved by the GSFC COTR.

6.2 ANALYSIS

Verification of performance or function through detailed analysis, using all applicable tools and techniques, is acceptable with GSFC COTR approval.

6.3 TEST

Represents a detailed test of performance and/or functionality throughout a properly configured test setup where all critical data taken during the test period is captured for review.

The Contractor shall take performance parameter measurements to establish a baseline that can be used to assure that there are no data trends established in successive tests that indicate a constant degradation of performance within specification limits that could result in unacceptable performance in flight.

6.4 TEST RESTRICTIONS

6.4.1 Anomaly During Tests

The Contractor shall halt a test, as appropriate, if an anomaly occurs during the test, to prevent potential damage to hardware and to preserve the failure configuration. The Contractor shall investigate anomalies in accordance with its approved procedures.

6.4.2 Modification of Flight Hardware

Once the formal test program has started, the Contractor shall not adjust or modify flight hardware unless this is documented and approved by the COTR prior to execution

6.4.3 Re-Test Requirements

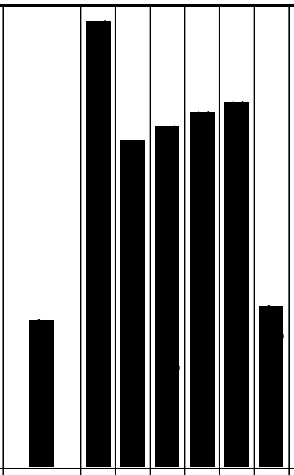
If any event, including test failure, requires flight hardware to be disassembled and reassembled, then the Contractor must consider repeating all tests performed prior to the event. The Contractor shall examine all the panels it has built or partially built to determine if the problem is common. If these require disassembly for repair, then each must receive the same test sequence.

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
AM0	Air Mass Zero
ANSI	American National Standards Institute
AR	Anti-Reflection
ASQC	American Society for Quality Control
ASTM	American Society for Testing of Materials
AWG	American Wire Gage
BOL	Beginning of Life
ºC	Degrees Centigrade
CCB	Configuration Control Board
CCR	Configuration Change Request
CIC	Covered, Interconnected Cell
cm	centimeters
CM	Configuration Management
CMO	Configuration Management Office
COTR	Contracting Officer's Technical Representative
CVCM	Collected Volatile Condensable Mass
DCR	Design Conformance Review
EOL	End of Life
GFE	Government Furnished Equipment
GSFC	Goddard Space Flight Center
Imp	Current at Maximum Power
Isc	Short-Circuit Current
JSC	Johnson Space Center
LRO	Lunar Reconnaissance Orbiter
MeV	Mega-electron Volts
MIL	Military
NASA	National Aeronautics and Space Administration
Pmax	Maximum Power
SA	Solar Array
SC	Spacecraft
SEE	Single Event Effects
SOW	Statement of Work
SPEC	Specification
STD	Standard
TID	Total Ionizing Dose
TQCM	Temperature Controlled Quartz Crystal Microbalances
V	Volts
Vdc	Volts direct current
Vmp	Voltage at Maximum Power
Voc	Open-Circuit Voltage
W	Watts

Appendix B. Schedule of Flight Panel Verifications

Order of Tests is Down Column; Then Move to the Next Column
Contractor may arrange order of tests in any column for convenience



End of Life Power	3.11	A										
Radius of Curvature	3.19.4	A										
Cleanliness	3.38.2		I	I		I	I					
Substrate Mass	3.19.1		M									
Cell Mechanical (Stereomicroscopic Inspection)	3.25.2			I		I	I					
Cover Orientation	3.26.2			I			I					
Indium Tin Oxide Resistance	3.26.6			M		M	M					
Panel Outgassing	3.21				M							
Panel Performance in Thermal Vacuum (Continuity Measurements)	5.1.1.1				M							
Panel Mass	3.19.2			M		M	M					
Insulation Resistance of Solar Panels	3.23			M		M	M					
Test Condition Power	3.5			M		M	M					
CIC Sensors	3.34			M		M	M					
Power at Highest Operating Temperature	3.7			M		M	M					
Power at Highest Predicted Temperature	3.9			M		M	M					
Bypass Diode Functionality	3.15			M		M	M					
Bypass Diode Functionality at High Temperature	3.17			M		M	M					
Blocking Diode Functionality	3.32			M		M	M					
	"A" represents an analytical verification											
	"I" represents verification by inspection											
	"M" represents verification by measurement.											

Appendix C. Schedule of Qualification Panel and Test Panel Assembly Verifications

Order of Tests is Down Column; Then Move to the Next Column
Contractor may arrange order of tests in any column for convenience

	Section Number	On Receipt of GFE Qualification Panel Substrate	After Completion of Panel Fabrication	After Panel Bend Test	During Thermal Vacuum and/or Bake Out	After Thermal Vacuum and Bake Out	After 100 Thermal Cycles	After 1000Thermal Cycles	After 5500 Thermal Cycles	After Final Repair			
Cleanliness	3.38.2	I	I	I		I	I	I	I	I			
Cell Mechanical (Stereomicroscopic Inspection)	3.25.1		I	I		I	I	I	I	I			
Cover Orientation	3.26.1		I							I			
Indium Tin Oxide Resistance	3.26.3		M	M		M	M	M	M	M			
Panel Outgassing	3.21				M								
QP Performance in Thermal Cycling (Continuity Measurements)	5.1.1.2				M								
TPA Performance in Thermal Cycling (Continuity Measurements)	5.1.1.3				M								
Substrate Mass Verification	3.19.1	M											
Panel Mass Verification	3.19.2		M			M	M	M	M	M			
Radius of Curvature Verification	3.19.4		M,I										
Insulation Resistance of Solar Panels	3.23		M	M		M	M	M	M	M			
Test Condition Power	3.5		M	M		M	M	M	M	M			
Power at Highest Operating Temperature	3.7		M	M		M	M	M	M	M			
Power at Highest Predicted Temperature	3.9		M	M		M	M	M	M	M			
Bypass Diode Functionality Verification	3.15		M	M		M	M	M	M	M			
Bypass Diode Verification at Hi Temperature	3.17		M	M		M	M	M	M	M			
Blocking Diode Verification	3.32		M	M		M	M	M	M	M			
	"I" represents verification by inspection												
	"M" represents verification by measurement.												

Appendix D. Earth-Moon Transfer Trajectory Radiation Environment*

**This environment is in addition to the lunar orbit radiation environment in the Lunar Reconnaissance Orbiter Radiation Environment Specification (431-SPEC-000020)*

Solar Proton Spectrum for LRO Transfer Trajectory

Energy (> MeV)	Proton Fluence (p/cm^2/mission)
0.1	3.20E+09
0.5	2.83E+09
1	2.32E+09
2	1.55E+09
3	1.05E+09
4	7.92E+08
5	6.38E+08
6	5.40E+08
8	3.86E+08
10	2.80E+08
12	2.10E+08
15	1.52E+08
17	1.28E+08
20	1.05E+08
25	7.30E+07
30	5.11E+07
35	3.82E+07
40	2.88E+07
45	2.24E+07
50	1.86E+07
60	1.32E+07
70	9.00E+06
80	6.47E+06
90	4.52E+06
100	3.54E+06
120	2.09E+06
140	1.44E+06
160	1.02E+06
180	7.55E+05
200	5.89E+05

Trapped Electron Spectrum for LRO Transfer Trajectory

Energy (> MeV)	Electron Fluence (e/cm^2/mission)
0.04	8.20E+12
0.1	5.04E+12
0.2	2.55E+12
0.3	1.47E+12
0.4	9.60E+11
0.5	6.43E+11
0.6	4.76E+11
0.7	3.56E+11
0.8	2.79E+11
1	1.86E+11
1.25	1.18E+11
1.5	7.54E+10
1.75	4.86E+10
2	3.15E+10
2.25	2.07E+10
2.5	1.37E+10
2.75	8.51E+09
3	5.29E+09
3.25	3.25E+09
3.5	2.00E+09
3.75	1.13E+09
4	6.42E+08
4.25	3.41E+08
4.5	1.82E+08
4.75	8.90E+07
5	4.51E+07
5.5	9.74E+06
6	1.91E+06
6.5	3.34E+05
7	3.21E+04

Trapped Proton Spectrum for LRO Transfer Trajectory

Energy (> MeV)	Proton Fluence (p/cm^2/mission)
0.1	7.80E+12
0.15	6.11E+12
0.2	4.83E+12
0.3	3.25E+12
0.4	2.22E+12
0.5	1.57E+12
0.6	1.12E+12
0.7	8.24E+11
1	3.45E+11
1.5	1.00E+11
2	3.43E+10
3	1.05E+10
4	4.20E+09
5	2.41E+09
6	1.47E+09
7	1.02E+09
10	4.13E+08
15	1.54E+08
20	8.83E+07
30	5.10E+07
40	3.97E+07
50	3.17E+07
60	2.71E+07
70	2.34E+07
100	1.55E+07
150	8.26E+06
200	4.50E+06
300	1.55E+06
400	5.45E+05